FC/BT

Center for Fuel Cell & Battery Technologies

Dr. David Parekh, *Director*

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Georgia Institute of Technology

www.fcbt.gatech.edu

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Vision for Center

- ***Catalyst*** for revolutionary advances in fuel cell and battery technologies through world-class research integrated across disciplines and transitioning fundamental discovery to system-level innovations.

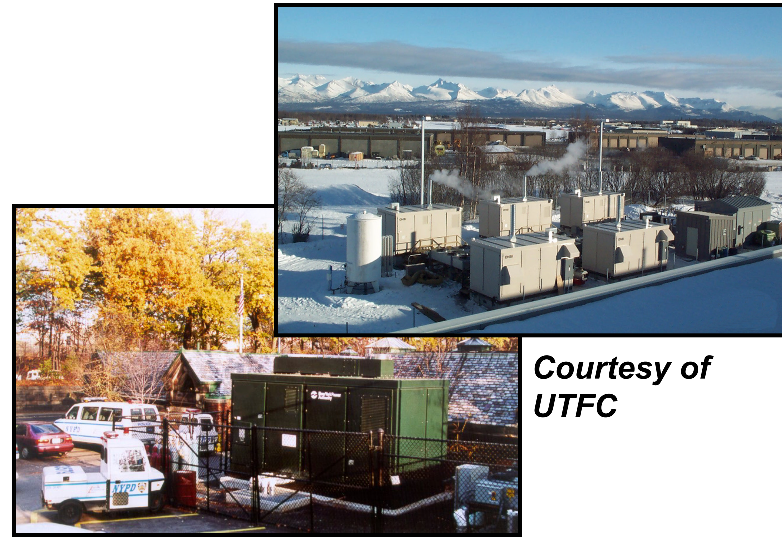
- ***Partnership*** with leading industry & government organizations to provide enabling technologies and to assist in commercial product realization.

- ***Educational service*** to a broad range of clients, including industry professionals, university students, and aspiring (K-12) scientists & engineers.

- ***Magnet*** for economic development

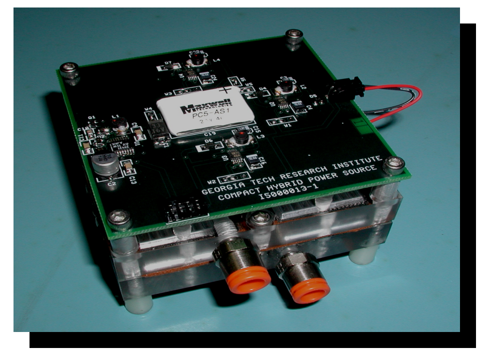
Market Focus

- Distributed stationary power supplies

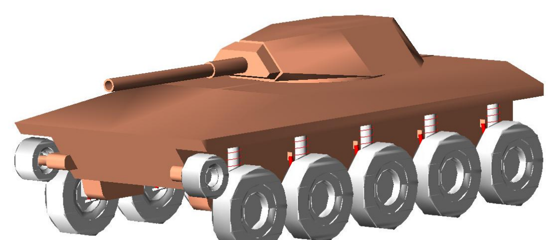


Courtesy of UTFC

- Compact power sources for portable and remote applications



- Vehicle applications



Core Capabilities

- Electrochemistry and materials science
- Nanostructured materials & MEMS fabrication
- Fuel processing
- Fluid dynamics, acoustics, and controls
- Simulation and modeling
- Advanced manufacturing processes
- Power electronics, transmission, and distribution (joint with NEETRAC)
- Systems-level integration and applications

Educational Activities

- Integrating fuel cell topics in senior design projects
- Developing fuel cell certificate program that would include ChE, MSE, EE, ME courses
- Linking students and faculty with industry partners through co-op, and visiting scientist exchange programs
- Offering series of on-site and distributed short courses on fuel cell fundamentals, systems engineering, and applications
- Focused special topic workshops on technology and policy
- Monthly distinguished lecture series
- K-12 teacher training and resource development

Research Activities

- Fundamental research in core disciplines
- Applied research at component and system levels targeted toward maturing technology readiness
- Partnership in product development
- System demonstrations and independent testing
- Various venues for in-depth research collaborations

Research Highlights

- Development of thin-film electrolytes and mixed-conducting electrodes for fuel cells
- Modeling of molten carbonate and solid oxide fuel cells
- Extending fuel cell technology for use with electrochemical membrane devices that clean fuels/gases
- Enabling technologies for compact, small-scale or micro proton exchange membrane fuel cells
- Development of an advanced room-temperature, sodium-based battery for high power and energy density
- Development of new electrode alloys and polymer electrolytes for lithium batteries
- Development of new methods for faster, more efficient battery charging and state of charge estimation
- Modeling of battery power sources for electric and hybrid-electric vehicle designers and users

Recent FC/BT Awards

- DARPA: Palm Power 20-W Solid-Oxide Fuel Cell
  MEMS mW-scale Direct Methanol Fuel Cell
- ONR: System Modeling of Advanced Propulsion for MEFFV
- Army: 8-year Collaborative Technology Alliance
  (with Honeywell and Motorola)
- DOE: Solid-State Energy Conversion Alliance
- NASA URETI: Auxiliary Power Fuel Cell System for Future Aircraft
- NSF: Electrode Materials & Fuel Cell Transients Modeling
- Allied Utilities: Alkaline Fuel Cells for Distributed Power
- Ford: Rapid Battery Charging & State of Charge Estimation
- GTRI IRAD: Compact High Energy Density Power Source
  & Fuel Reforming and Humidity Control for PEM

Projections for Hybrid Metal/Ceria Monolithic SOFC

Joe Cochran, Jim Lee, Meilin Liu, Dave McDowell,Tom Sanders
Schools of Materials Science and Mechanical Engineering

1. Operation Fuels -- Hydrogen, Natural Gas, Propane, Coal Gas, Methanol, Ethanol, and Reformed Gasoline and Diesel; potentially insensitive to contaminants such as H_2S in reformed fuels.

2. Power Density – 1Watt/cc in Near Future, 5 Watts/cc in 3-4 Years

3. Operating Temperature – 400-600^{0}C

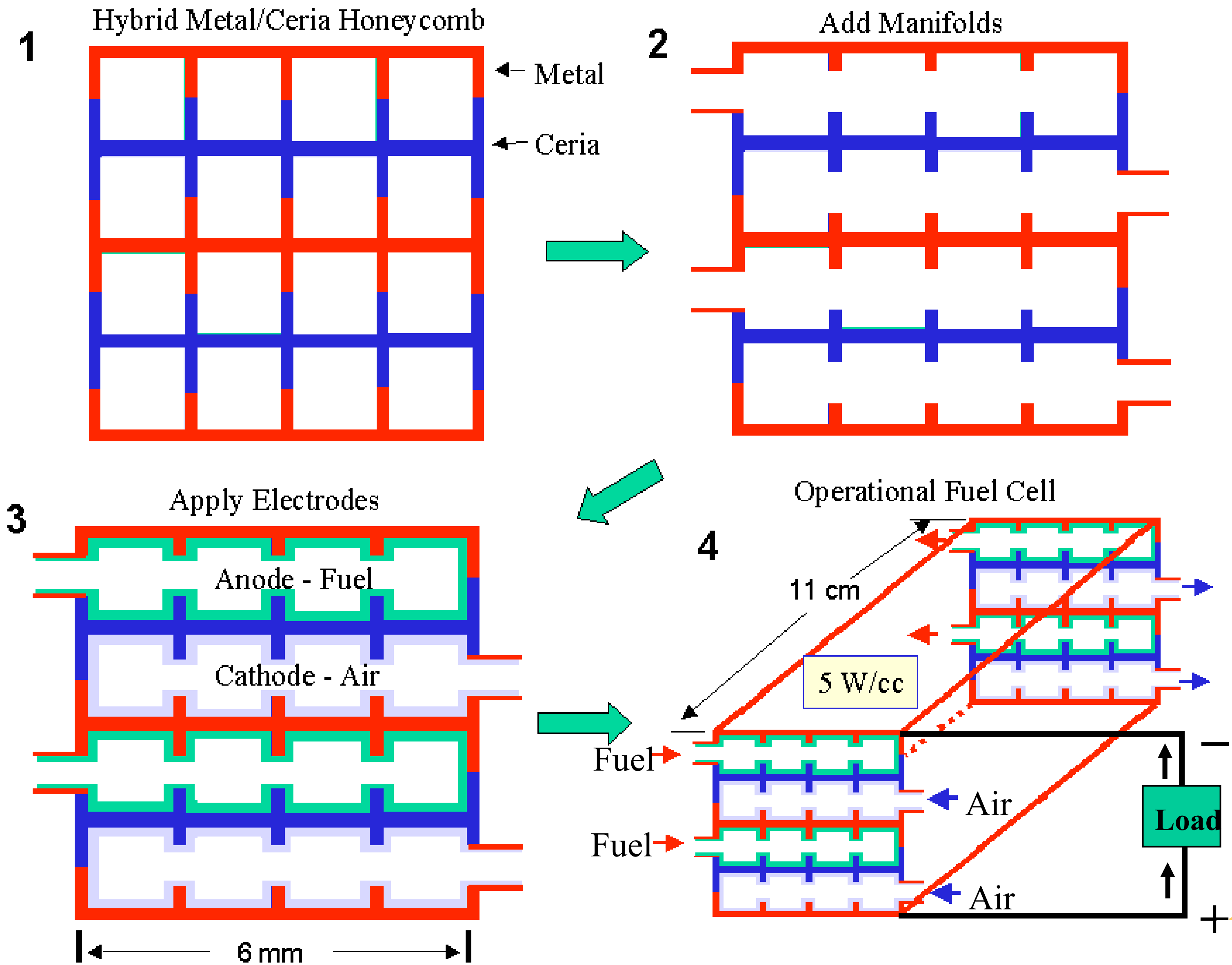
4. Fuel Cell Size – 6 X 6 mm square by 11cm long. (This Is 4 Watts at 1 W/cc and 20 watts at 5 W/cc. (This Is Not Palm Power. It Is Finger Power)

5. Materials – Samaria Doped Ceria (SDC) Solid Electrolyte, CoCr Doped Ni Metal Interconnect, Anode of Porous Ni-SDC, and a Cathode Layer, Consisting of $Sm_{0.5}Sr_{0.5}CoO_3$ and 10wt.% SDC. Catalysts Will Be Added As Needed Depending on Fuel.

6. Cost -- $500/kilowatt in One Year, $50/kilowatt in 3-4 Years

Sponsored by DARPA Palm Power

Hybrid Metal/Ceria Monolithic SOFC



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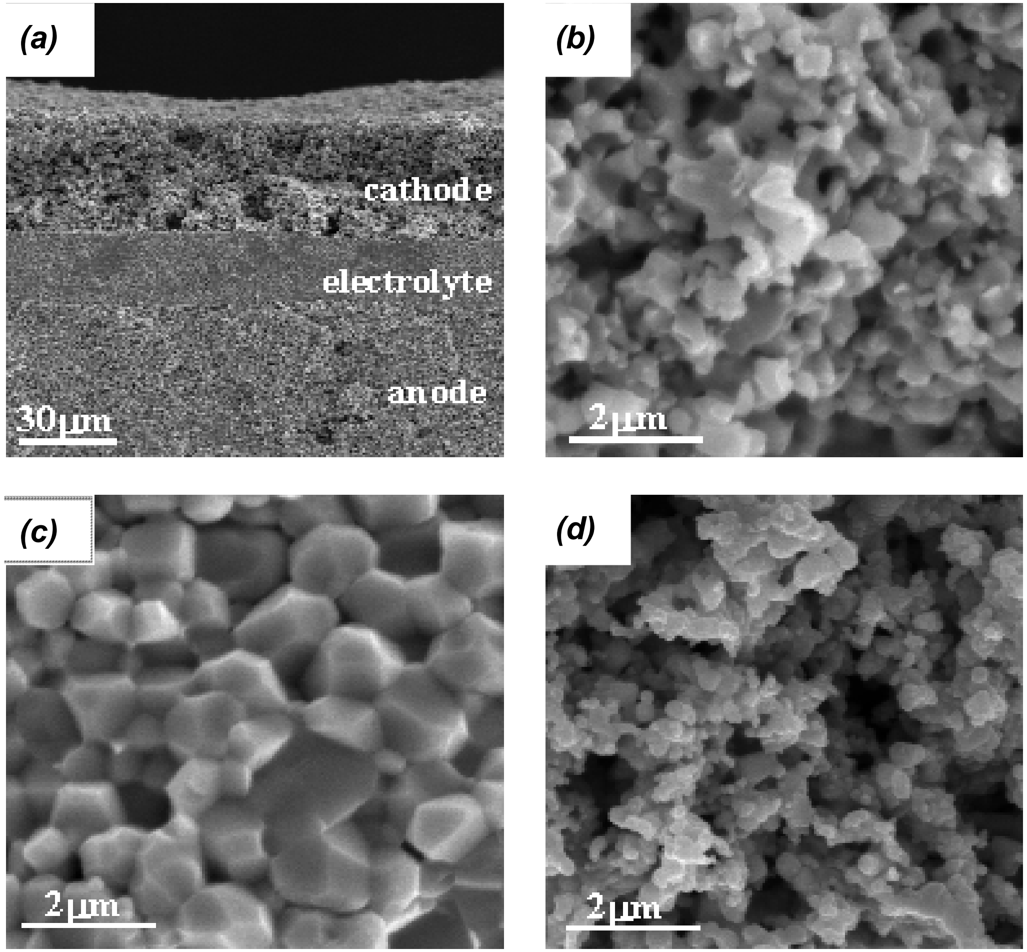
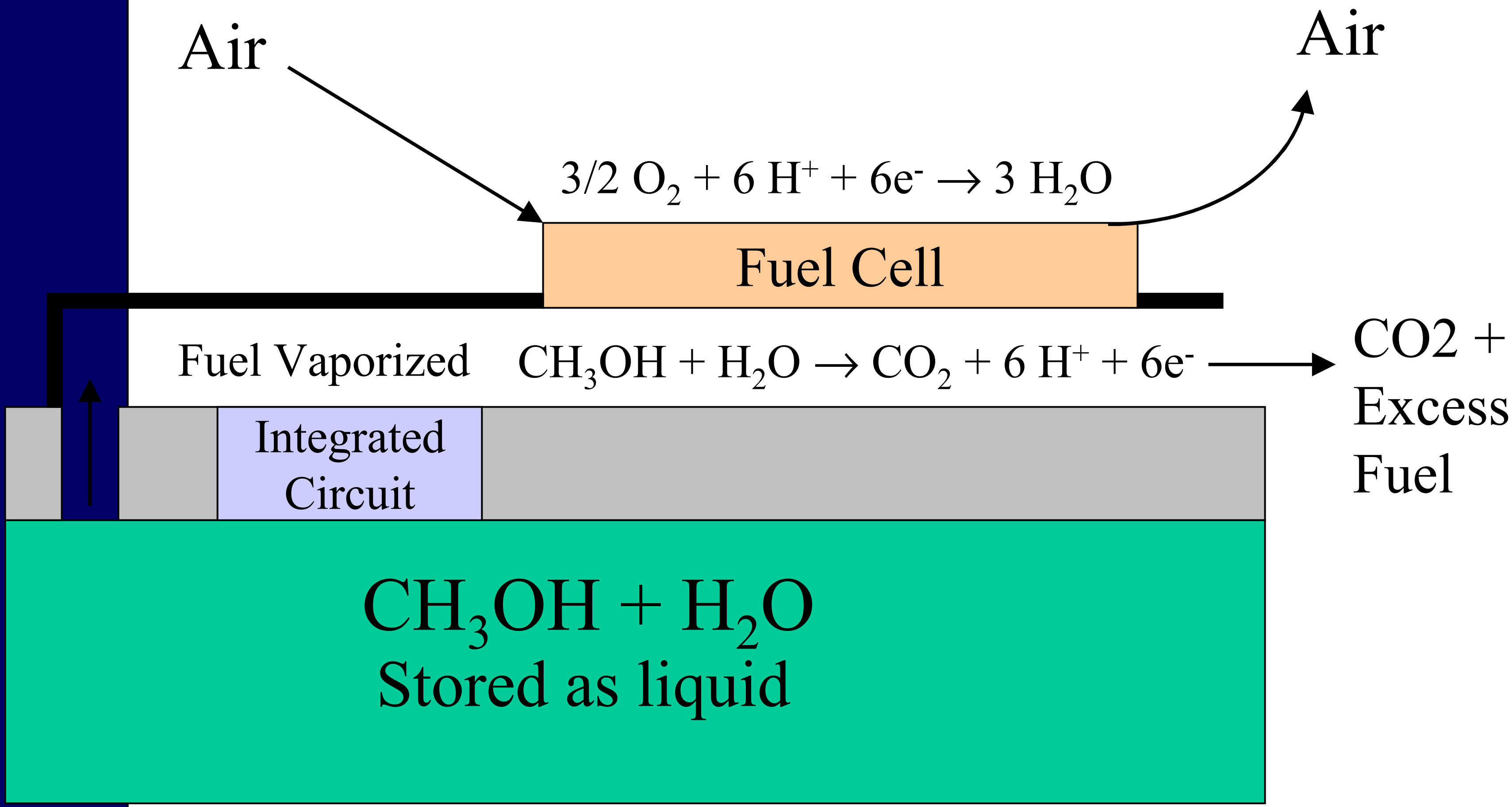
Microstructured Materials Enable Low-Temperature Solid-Oxide Fuel Cell



Cross-sectional views (SEM micrographs) of
(a) a single cell, (b) the porous Ni-SDC anode, (c) the dense SDC electrolyte,
and (d) the porous $Sm_{0.5}Sr_{0.5}CoO_3$ + 10wt.%SDC cathode.

Integrated Micro-Fuel Cell

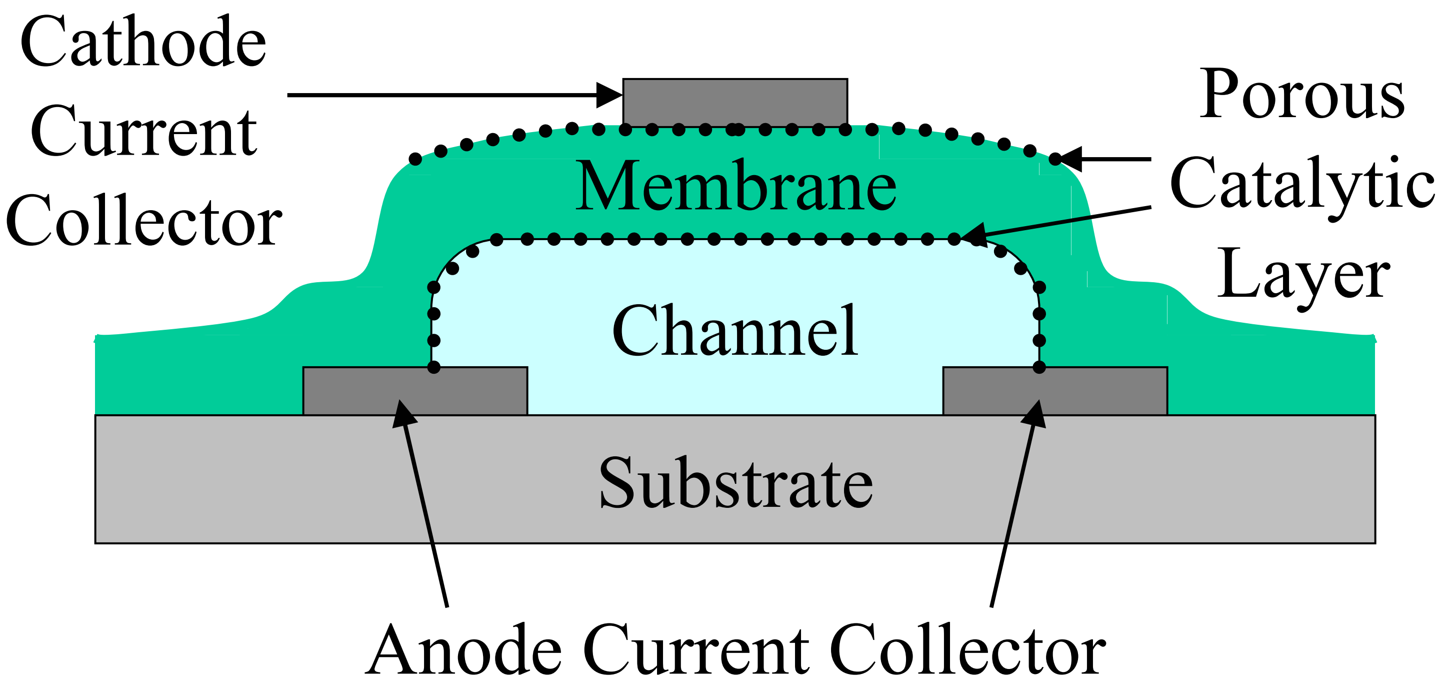
–Kohl, Hesketh (GT) & Wainright, Litt (CWRU)

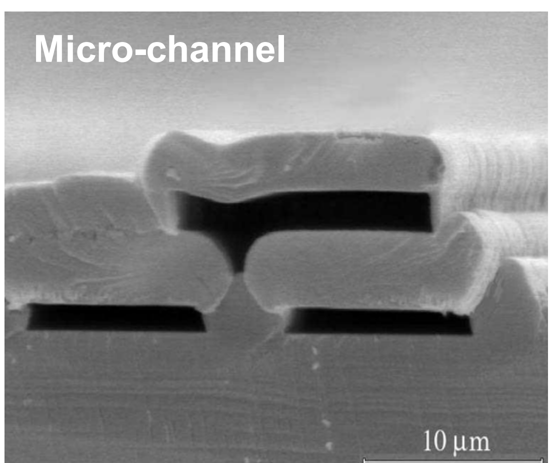


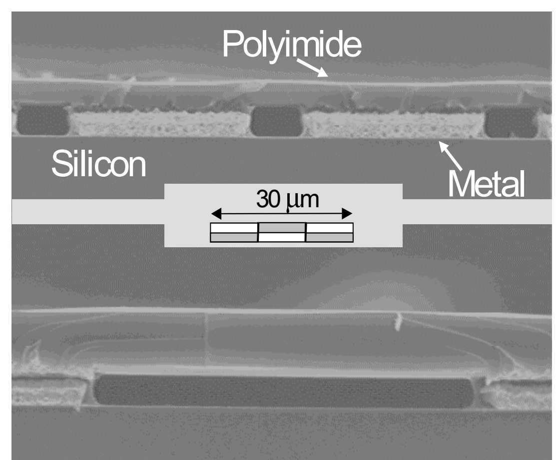
1 mW power at 0.4 V, 50% efficiency, no crossover

(10 cc = 119 days of operation)

Micro-Fuel Cell







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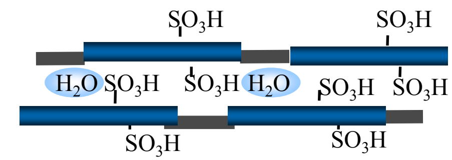
Novel Polyelectrolyte Membranes

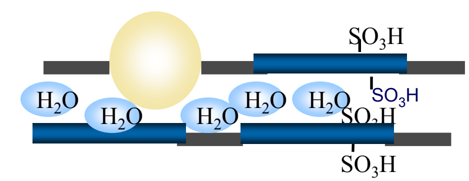
Molecular Design

The rigid-rod liquid crystalline feature enables bulky comonomer units to separate the polymer creating pores lined with SO_3H/;water groups.

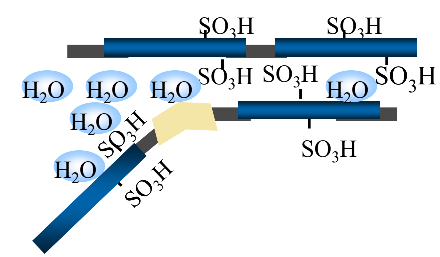
(a). Homopolymer or copolymer with linear, small comonomer



(b). Copolymers with linear, bulky comonomer



(c). Copolymers with angled, and/or rigid comonomers

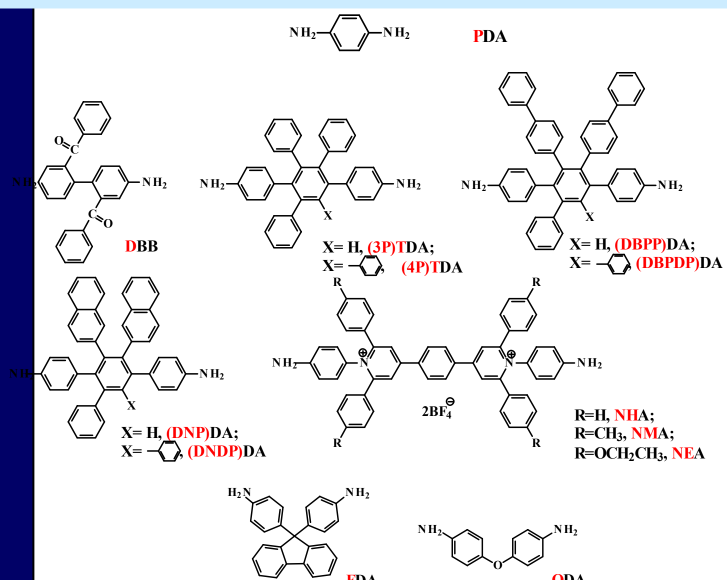


Categories and structures of comonomers.

(a)

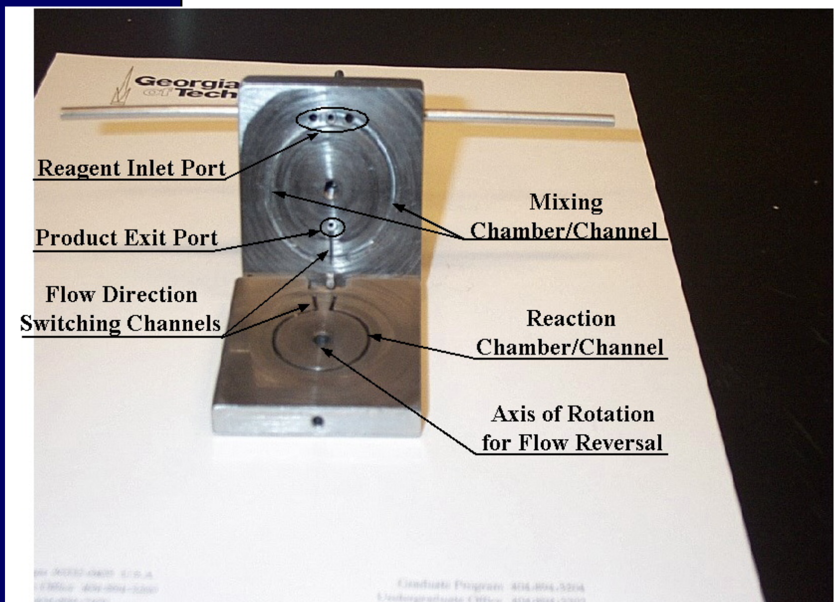
(b)

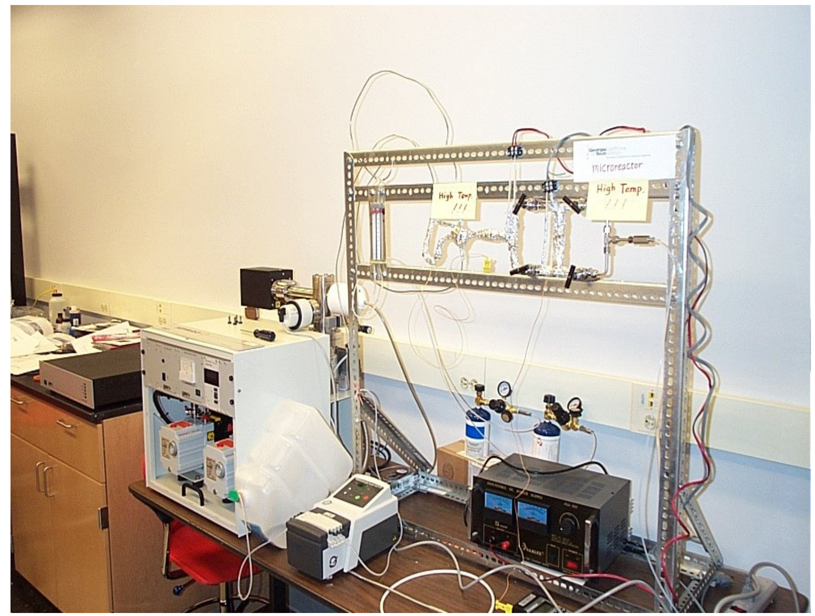
(c)



Reverse-Flow Autothermal Catalytic MEMS Hydrogen Generator (*Patents Pending*)

(A. Fedorov)





Reactor

Experimental Rig

Support: Air Products & Chemicals, Inc.

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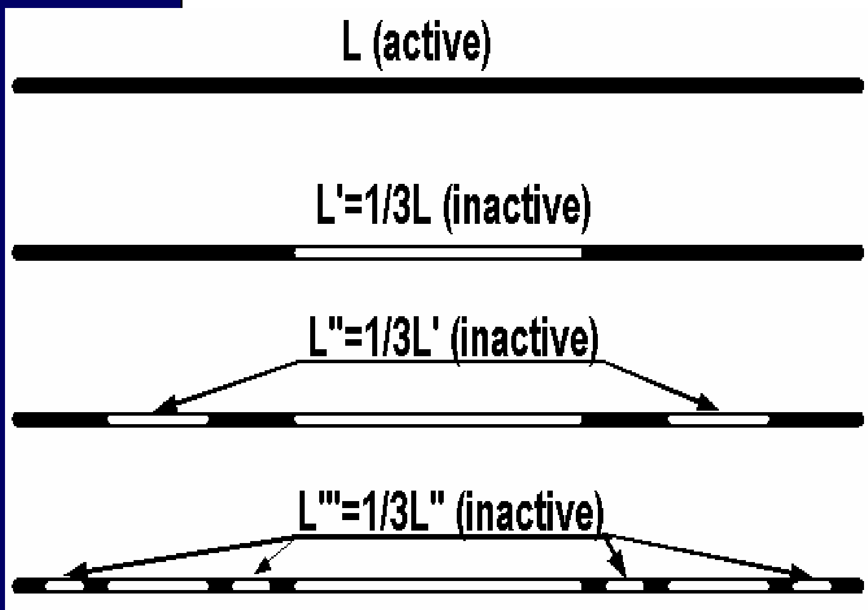
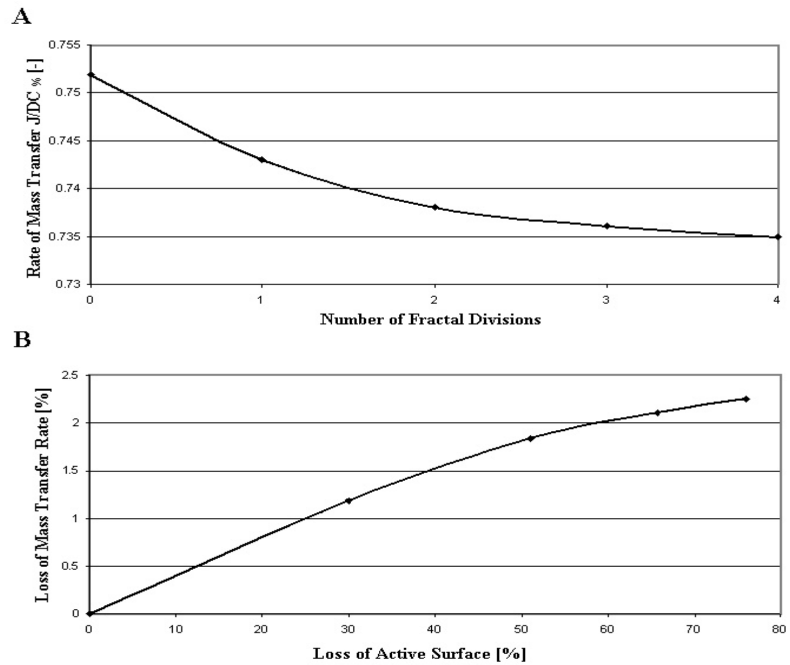
Fractal-Based Spatial Patterning of Catalytically Active Surfaces

(A. Fedorov)





Active Surface Structuring **Simulation**

***Conclusion*: 75% reduction in catalyst loading can be achieved with only 2% decrease in the reaction conversion rate**

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Compact High-Energy Density Power Cell

A. Williams, G. Gray, G. Richardson, M. Entrekin, R. Ivey, and C. Jameson

Micro Fuel Cells

- *20 Year Life may be Possible*
- *Extremely Reliable*
- *Environmentally Friendly*
- *High Energy Density*
- *Provide a Low Level Continuous Output Current*
- *Low Output Voltage*

Energy Management System

- Transforms the fuel-cell output voltage to a level that will maximize efficiency of the peak power storage capacitor
- Develops voltages and currents capable of supplying real-world loads
- Provides Efficient Load Regulation
- Must Operate at Extremely Low Supply Voltages

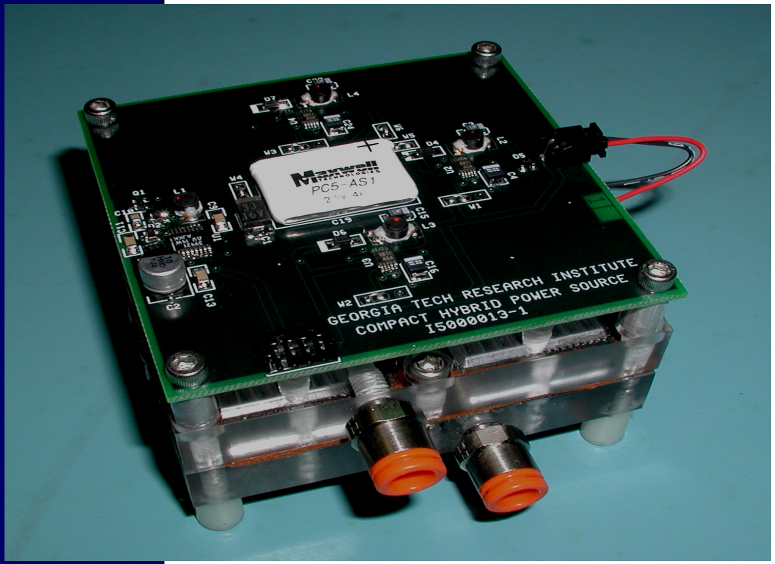
High Energy Density Storage Capacitors

- *20 Year Life*
- *Extremely Reliable*
- *Environmentally Friendly*
- *High Power Density*
- *Can Provide High Peak Current on Demand*

Energy Management System Challenges

- Conversion circuitry must be very compact
- Must operate from very low power supply voltages
- Simultaneous use of high frequencies, high voltages, and high currents in a compact package produces extreme EMC issues.
- Must produce “clean” and regulated output power.
- Fuel cell must be configured to maximize efficiency of energy conversion circuitry
- Energy conversion topology must be configured to optimize life of electrochemical capacitor.

Hybrid Power Source Demonstrator Module



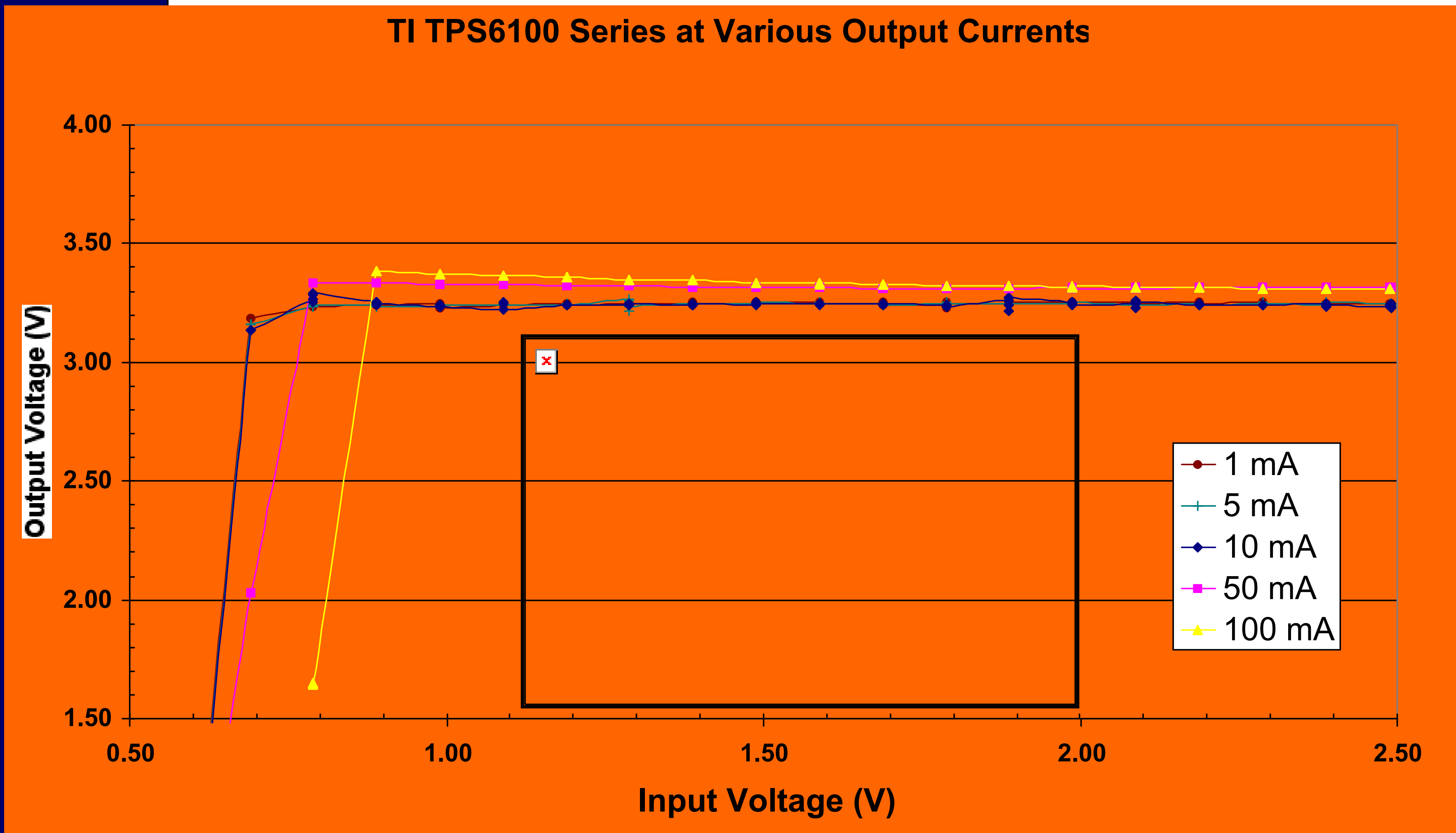
- **Total Average Power 600 mW**
- **Instantaneous Power Available 20 W**
- **Can Provide 1 A Peak at 3.3 to 28 V as Configured**
- **10 A Peak can be Delivered at 2 V!**

- **Output 1**
  - 3.3 VDC
  - 100 mA Average
  - 86 % Efficiency from 10 to 60 mA

- **Output 2**
  - 3.3 VDC
  - 100 mA Average
  - 1 A Peak
  - 74 % Efficiency Achieved

- **Output 3**
  - 2 to 28 VDC
  - 15 mA Average
  - 1 A Peak
  - 72 % Efficiency Achieved

Performance under Varying Loads



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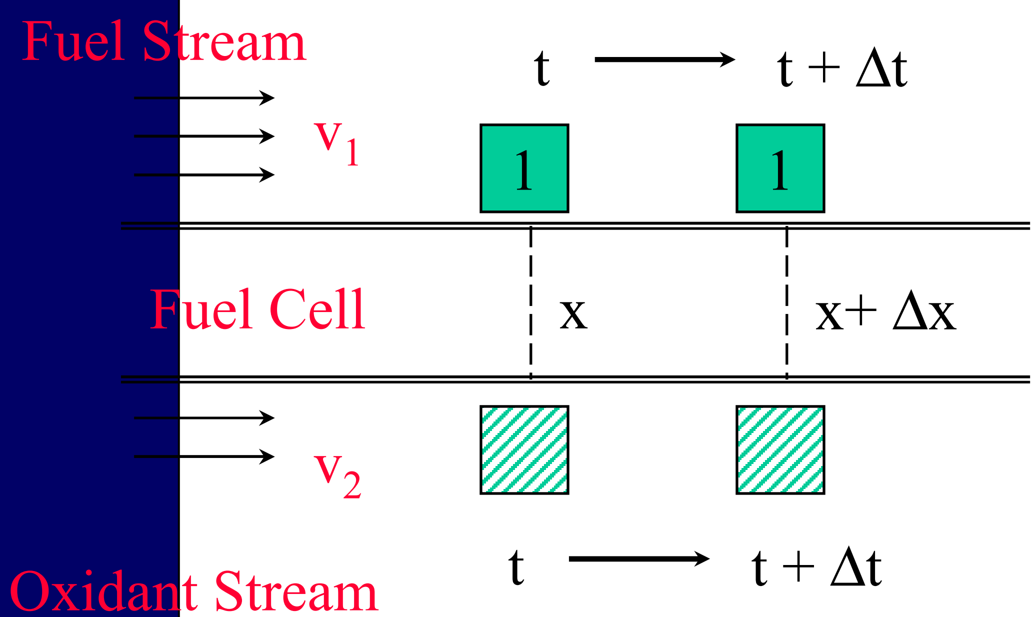
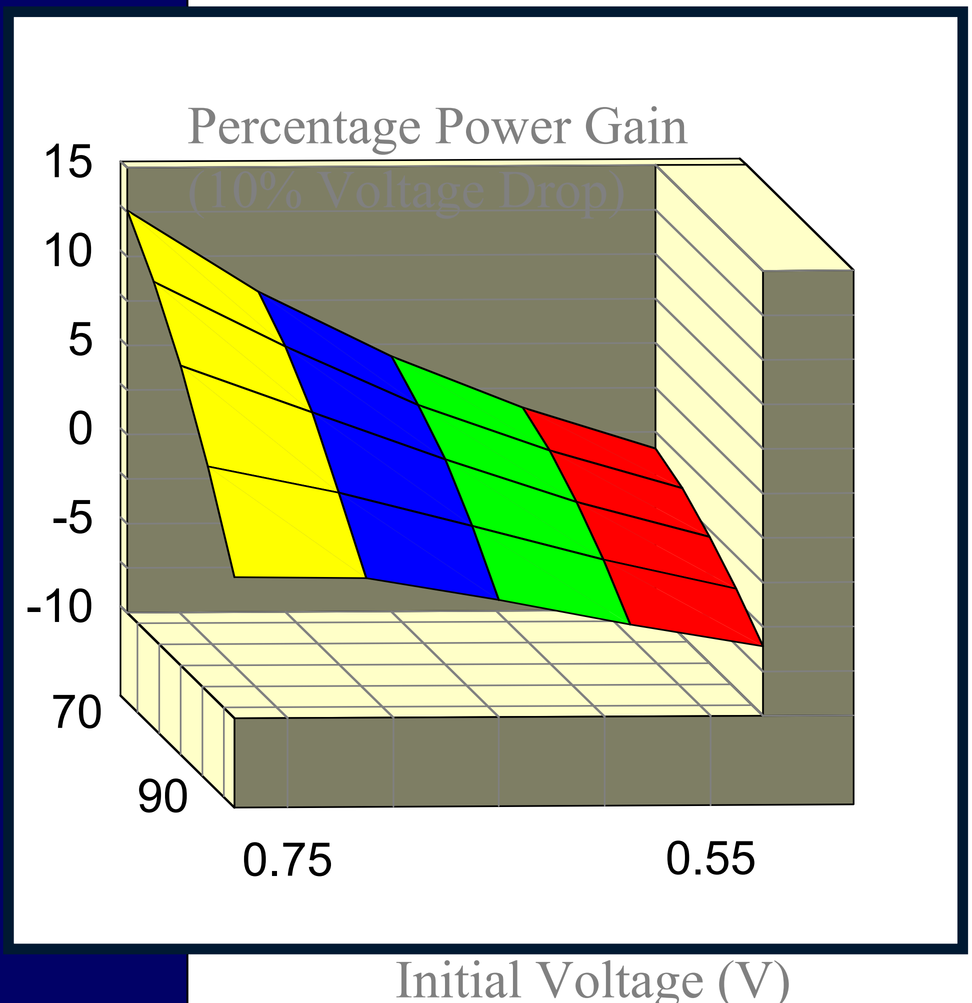
Lagrangian Extension of Steady State Model to Simulate Transients During Load Following
(C. Haynes)

$$\eta_{element}(t+\Delta t) = \eta_{field}(x+\Delta x, t+\Delta t)$$



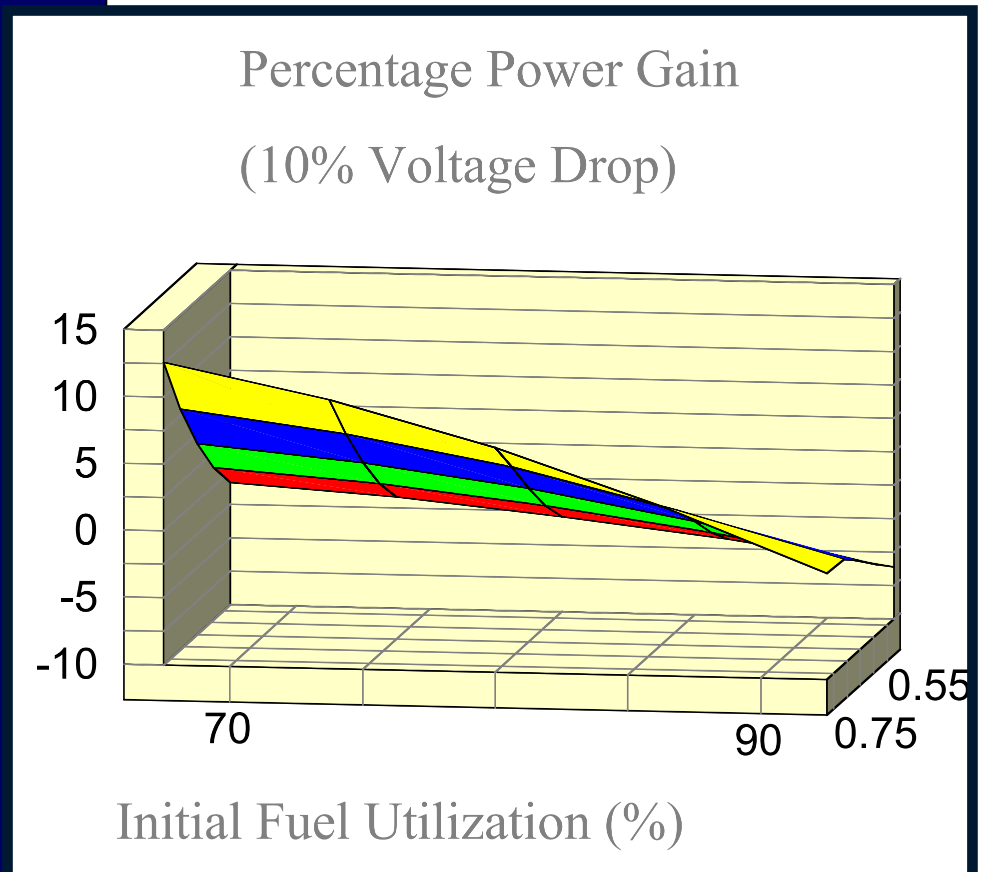
Element properties were calculated by using the proven steady state model on an instant-by-instant basis until a new electrical steady state was reached

Settings for Reliable Load Following: Increase Initial Operating Voltage



- At typical operating conditions, the ohmic losses are dominant (parabolic P-V curve with a maximum)
- At higher operating voltages, reductions in potential thus cause greater increases in power due to the steeper P-V slope

Settings for Reliable Load Following: Decrease Initial Fuel Utilization in Cell Stack



- Lower fuel utilization allows for higher fuel concentrations along the fuel cell
- Virtual fuel reserve/ fuel buffer along the cell guards against reactant depletion issues and minimizes power dips

New GTRI Fuel Cell & Battery Technology Lab

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Business Considerations

- Georgia Tech Industry Contracting and Technology Licensing Offices streamline negotiations of terms and conditions and intellectual property agreements that satisfy both corporate and university constraints

- Internal processes provide excellent due diligence for handling proprietary information

- ATDC (Advanced Technology Development Center) incubator and growing local venture capital resources provide fertile climate for new business start-ups

Summary

- Research integrated across disciplines
- Systems approach to technology development for a variety of fuel cell types and applications
- World-class faculty and students
- "Field of Dreams" approach to developing infrastructure and critical mass of researchers and programs
- Opportunity for companies to leverage strong research base and capabilities through individualized partnerships

Benefits of Long-Term Strategic Partnership

- Collaborative research to expand core capabilities, provide system design tools, and accelerate technology development
- Effective recruiting through early and continued access to high-quality students
- Improved training through various education options
- Enhanced visibility for companies through use and demonstration of their components and systems
- Foundation grants, research contracts, and basic ordering agreements provide options for streamlined business arrangements